AR-010-249

DSTO-TR-0545

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L.V. Krishnamoorthy, R. Glass and D.R. Kirk

DSTO-TR-0545

19971007 172

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# Measurement of Drag Characteristics of Mk 82 General Purpose Low Drag Bomb using an Aeroballistic Range Facility

*L.V.Krishnamoorthy, R.Glass and D.R.Kirk*

**Weapons Systems Division**
**Aeronautical and Maritime Research Laboratory**

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## ABSTRACT

A method is described to determine the drag characteristics of the Mk 82 low drag bomb. This involves launching half scale models from the DSTO gas gun facilities at Port Wakefield and measuring the trajectories by photogrammetric methods. The drag coefficients were calculated from the measured positional data using a three degrees of freedom parameter estimation method. The estimated drag characteristics of various Mk 82 GPLD store configurations will form the basis of a database for use with the updated F-111C aircraft.

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*Published by*

*DSTO Aeronautical and Maritime Research Laboratory*
*PO Box 4331*
*Melbourne Victoria 3001*

*Telephone: (03) 9626 7000*
*Fax: (03) 9626 7999*
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*AR-010-249*
*June 1997*

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# Measurement of Drag Characteristics of Mk 82 General Purpose Low Drag Bomb using an Aeroballistic Range Facility

## Executive Summary

The F-111C Avionics Update Program (AUP) will introduce a unique aircraft which has a digital weapon system with integrated avionics equipment employing embedded software for all major avionics functions including weapon delivery. The update involves replacing the analogue ballistic computer unit in the weapon delivery system with a digital counterpart to calculate the bombing solution.

The trajectory calculation in the mission computer relies heavily on the free stream aerodynamic characteristics of the store. The aerodynamic characteristics are commonly estimated from wind tunnel testing using scaled models, computational fluid dynamic (CFD) methods, aeroballistic range trials and free flight full scale store drops.

The weapon delivery system has an aerodynamic data base for all the weapons carried by the parent aircraft. The data base is usually tabulated values of drag (ballistic) coefficient ( $C_D$ ) against Mach number (M) over the flight regime of the weapon. The data base is normally in the form of curve fits.

The Mk 82 General Purpose Low Drag (GPLD) bomb is the primary gravity drop weapon carried on the RAAF F-111C and F/A-18 aircraft. There are some shortcomings in the quality of data that RAAF has been able to provide to the AUP contractors. The drag characteristics of the bomb seem to have been derived by scaling Mk 83 store data. The scaling approach is not necessarily valid for RAAF weapons, furthermore, the origin of the data is not known. Hence there is a need to establish the data base for Mk 82 GPLD bomb.

In this report we discuss in detail the drag characteristics of Mk 82 GPLD bomb as obtained from aeroballistic range trials conducted by Weapons Systems Division (WSD) using a well tested photogrammetric technique.

Mk 82 GPLD bomb has various configurations depending on the aircraft on which it is carried. Aeroballistic Range trials have been carried out on half scale Mk 82 models covering all different configurations over a Mach Number range, 0.5<M<1.2. The drag characteristics are obtained for a clean Mk 82 bomb along with the add on such as lugs (T-type and D-type), fuzes (nose and tail).

The aerodynamic data resulting from these trials will serve several purposes. First, it will be included in the aerodynamic data base currently assembled for Mk 82 GPLD bomb using data obtained from different sources such as wind tunnel, full scale drops

from F/A-18 aircraft and CFD calculations. The assembled data base will then be used in the mission computer software of the post AUP F-111C aircraft.

The results from this study will provide the customer/client with the accurate drag characteristics for the Mk82 General Purpose Low Drag bomb required to achieve the specified accuracy in the miss distance estimations. Further, the incremental approach used here would enable the estimation of changes to the drag characteristics due to modifications to the stores (e.g. fuze change) with minimum effort, resulting in valuable cost savings.

# Authors


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# Contents

# 1. Introduction

The F-111C Avionics Update Program (AUP) will introduce a unique aircraft and software configuration into RAAF service. The digital weapon system has integrated avionics equipment employing embedded software which will control most of the aircraft sub systems such as flight control, radar, navigation, detection, communication and weapon delivery.

The update involves replacing the analogue ballistic computer unit in the weapon delivery system with a digital counterpart to calculate the bombing solutions. The process of providing weapon aiming data for all the ballistic weapons that F-111C aircraft has in its inventory requires:

(a) Aerodynamic data for the weapon in the free stream environment,
(b) Aircraft release point parameters,
(c) Ballistic computations, and
(d) Empirical estimation of the effect on the weapon of separation and transit through the aircraft flow field.

The ballistic computer in the weapon delivery system has an aerodynamic database for all its weapons. This database consists of tabulated values of aeroballistic (drag) coefficient against Mach number over the flight regime of the weapon. The database is normally in the form of curve fits. The trajectory algorithm in the mission computer (MC) will be as close as possible to the Reference Ballistic Trajectory Model (RBTM) described in reference 1. The RBTM uses a three degrees of freedom model in its computations and the only aerodynamic coefficients necessary are the zero yaw drag values.

There are some shortcomings in the quality of data that RAAF has been able to provide as part of their AUP commitments. For instance, the aerodynamic characteristics for the Mk 82 bomb have been derived (ref 1) by scaling Mk 83 bomb data, thereby introducing errors of scale. Further the origin of the original database corresponding to Mk 83 General Purpose Low Drag (GPLD) bomb is not known. This scaling approach is not necessarily valid for a RAAF primary gravity weapon. Hence there is a need to establish a better quality database for Mk 82 GPLD bomb.

There are many ways of obtaining estimates of the drag coefficient versus Mach number. The main ones are as follows:

(1) Theoretical estimation using fluid dynamic theory.
(2) Empirical estimation using data on similar bomb shapes.
(3) Wind tunnel testing using a scaled model.
(4) Aeroballistic range testing using either scaled or actual stores.
(5) Free flight full scale drops.

The work reported here is in response to an Air Force Research Requirement (AFRR) 7/90, 'F-111C/RF-111C Modelling', Supplement 1. Amongst other things, AFRR assistance from the Defence Science and Technology Organisation (DSTO) to review the contractor's stores clearance plan, develop and maintain the RBTM program and compile ballistic data of stores specified for use in the post-AUP F-111C aircraft system.

This report discusses in detail the aerodynamic characteristics of Mk 82 GPLD stores as obtained from the aeroballistic range trials conducted by the Weapons Systems Division (WSD) using well tested photogrammetric techniques. The principal aim of these trials is to establish the trends in the incremental change of the drag coefficient with the addition of lugs and fuzes. It is hoped that this knowledge will not only help to construct the drag database of fully configured Mk 82 bombs, but also reduce experimental measurements for future modifications.

Section 2 describes the Mk 82 GPLD bomb configuration and its physical characteristics. Section 3 describes the half scale aeroballistic model construction and assembly procedure followed during the trials. Section 4 describes the aeroballistic range instrumentation, the procedure for processing ballistic camera images and the calculation of trajectory of the bomb using the various camera images. Section 5 deals with the equations of motion of the bomb. Section 6 describes in detail the 3 degrees of freedom (3dof) parameter estimation model to obtain the aerodynamic drag coefficient. Section 7 presents, in detail, the calculation of drag coefficients using the 3dof model as applied to a particular trial data. The drag coefficient of a clean Mk 82 GPLD bomb as a function of Mach number, as obtained from the trials data, is described in Section 8 and in Section 9 the effect of additions such as lugs (both T and D type), nose (M904) and tail (ATU-35) fuzes on the drag characteristics is discussed.

# 2. Mk82 GPLD Bomb Description

The 500 lb (225 Kg) General Purpose Low drag Bomb (Figure 1) has a slender body with a long tapered nose. A Mk 82 conical-type fin (MAU-93/B) is attached to the aft end of the bomb body. The fin assembly has a 1.5° cant to induce spin for stability. Depending upon the aircraft type, the Mk82 bomb can be configured with either a T-Lug (BRU rack in F-111C aircraft) or a D-Lug (F/A-18) for carriage attachment. Further, the bomb can be used with proximity, mechanical or electrical fuzes. The type of fuzes used are the M904; an impact fuze designed to fit in the nose of the bomb, and the M905; an inertial type of fuze to fit in the tail section.

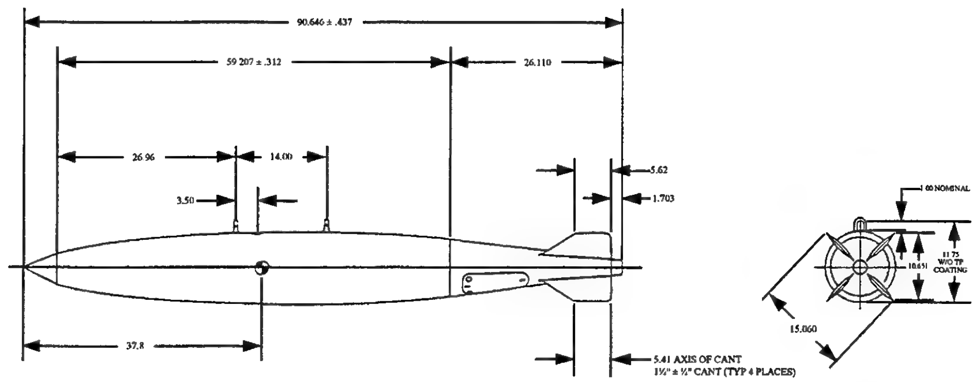


*Figure 1. Layout of Mk 82 General Purpose Low Drag (GPLD) 500 lb bomb (all dimensions in inches)*

The physical characteristics of Mk 82 GPLD bomb are given in the reference 2 and are reproduced in Table 1.

*Table 1: Physical Characteristics of 500 lb (225 Kg) Mk82 GPLD Bomb*

| Parameter | Imperial units | Metric units |
|---|---|---|
| Length, assembled | 90.65 inches | 2.30 m |
| Body diameter | 10.65 inches | 0.27 m |
| Fin (conical type) | | |
| Span | 15.1 inches | 0.3835 m |
| Chord | 10.6 inches | 0.2692 m |
| Weight | 24 lb | 10.9 Kg |
| Total weight (nominal)[1] | 531 lb | 240.9 Kg |
| Explosive weight(nominal)[2] | 192 lb | 87.1 Kg |
| Case weight (nominal) | 311 lb | 141.1 Kg |
| Centre of Gravity (from nose) | 37.8 inches | 0.96 m |
| Moments of inertia | | |
| Pitch | 36.7 slug ft$^2$ | 49.8 Kg m$^2$ |
| Yaw | 36.7 slug ft$^2$ | 49.8 Kg m$^2$ |
| Roll | 1.5 slug ft$^2$ | 2.0 Kg m$^2$ |

[1] Filled with H-6, Tritonal, or Minol II
[2] Filled with H-6 or Tritonal

# 3. Half Scale Mk82 GPLD model and trials

To obtain the aeroballistic characteristics of the Mk 82 bomb, it is necessary to know the effect of T-Lugs, D-Lugs and nose and tail fuzes, on the clean configuration. Hence a full trials program using the aeroballistic range facilities was initiated to produce a comprehensive database on the Mk 82 bomb for use in the Mission Computer software of the post AUP F111-C aircraft.

Using the DSTO aeroballistic range facilities (references 3, 4 and 5), flight dynamic studies have been carried out on half scale models of the Mk 82 GPLD store. The following configurations have been investigated:

- Clean Store (no lugs or fuzes),
- Clean + T-Lugs (pointed nose F-111C configuration),
- Clean + D-Lugs (pointed nose F/A 18 configuration),
- M904 nose fuze, D-Lugs and fins located in 45° position (F/A 18),
- M904 nose fuze, T-Lugs and fins located in 0/90° position (F-111C),
- M904 nose fuze, T-Lugs, ATU-35 arming drive assembly and fins located in 0/90° position.

## 3.1 Model Construction and Assembly

A half scale model of the Mk 82 GPLD bomb with varying types of lug and fuze configurations is shown in Figure 2. The model is constructed mostly of aluminium and has three sections. The front section houses the forward strobe light and has two possible configurations, either as a smooth pointed nose or with a dummy M904 fuze. The middle section houses the electronics and battery packs which cause the two high intensity optical strobe units to flash at a fixed frequency after the vehicle is launched. A detailed description of the instrumentation can be found in reference 6. Provisions for attaching either T or D Lugs are also included in the middle section. The rear section houses the thrust shaft, the rear strobe unit and the fin assembly. The position of the centre of gravity of the model is adjusted by adding lead ballast at the forward end of the model.

## 3.2 Half Scale Trial Procedure

Aerodynamic characteristics were obtained by launching the half scale models from a gas gun at the required muzzle velocity. AMRL has a number of smooth bore gas-operated guns, situated on two aeroballistic ranges, located adjacent to the RAAF base at Edinburgh and at the Army P&E Establishment at Port Wakefield. The Salisbury gun can be used only for subsonic velocities while the Port Wakefield range uses a 265 mm gun to launch projectile at transonic and supersonic velocities.

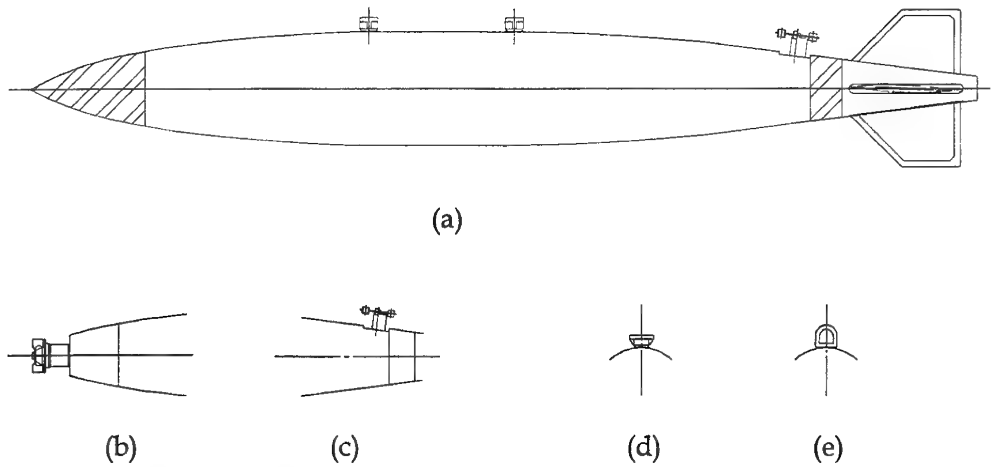


*Figure 2. Half scale model of Mk 82 GPLD bomb and components for its assembly into various configurations. Hatched portion in (a) represents the strobe units in the nose and tail; (b) M904 type nose fuze; (c) ATU-35 type tail fuze drive assembly (d) T-Lugs (e) D-Lugs*

# 4. Analysis of Range Data

## 4.1 Range Instrumentaion

The range instrumentation consists of ballistic cameras, reference light arrays located at intervals on, and on both sides of, the gun centre line of the range. The cameras and lights can be remotely operated from the gun position. The layout of these facilities, the associated instrumentation and the trials procedures are explained in detail in reference 6. The output of the trial is a negative film from each camera which contains the photographic images of a test vehicle's strobe units, the reference lights and the fiducial and identifying markers placed on the film by the camera.

## 4.2 Reading and Processing of the Camera Film Images

The hardware and software used in this process are fully described in reference 3. This section provides a brief summary.

### 4.2.1 Digitisation

The camera films are first developed to produce negatives, following which each negative is mounted in an optical comparator (or co-ordinate measuring instrument)

for the purpose of digitising the images. A video camera displays the images on a TV monitor at such a magnification as to clearly display the detail necessary for accurate, reproducible readings to be obtained. As the film carriage is moved to position each image under the cursor the X and Y co-ordinates are continually displayed on two six digit readout units and the computer monitor, and are also directed to an IBM compatible personal computer via a computer interface card, which acquires and stores the co-ordinates when the operator presses a button or foot pedal. The computer program requires the entry of both nose and tail strobe data but the data for each strobe unit is processed separately to produce two trajectories.

### 4.2.2 Derivation of Azimuth and Elevation Angles

When all the image co-ordinates from a camera film have been read into the computer, a data file is created to be used as input to a computation program to obtain the azimuth and elevation angles corresponding to each image reading. These are computed from the image positions on the film and data on the co-ordinates of the camera lenses and reference lights stored in a survey data file on the computer. This process is repeated for each camera film.

### 4.2.3 Calculation of Trajectory

The digital information from all the cameras is combined to obtain a solution for the position of each image, and hence the range, height and drift of the model against calculated flight time. Time information is computed from the flash rate of the strobe units on the test vehicle. An approximate solution is first calculated. This is then used as an initial estimate to start the iterative procedure to find a least squares solution providing an estimate of the image position which minimises the sum of the squares of the elevation and azimuth residuals for each camera.

# 5. Aerodynamic Coefficients

The aerodynamic coefficients are estimated using the maximum likelihood parameter estimation technique (references 7, 8, 9 and 10). The technique attempts to find the values for parameters characterising the mathematical model such that the sum of the squares of the differences between the model output (predicted response) and the input (observation vector) is minimum. The input vectors are the attitude angles of the projectile (pitch and yaw) and the three components of the velocity of the centre of gravity of the projectile.

The equations of motion of the C. of G. of a projectile are given by

$$\underline{F} = m\dot{\underline{u}} - m\underline{g}$$

$$\underline{M} = I\underline{h}$$

where $\underline{F}$ is the aerodynamic force, $\underline{M}$ the aerodynamic moment, $\underline{g}$ the gravitational force, $m$ the mass of the projectile, $\underline{u}$ (u,v,w) the three components of velocity, $\dot{\underline{u}}$ the acceleration vector, $\underline{h}$ (p,q,r) the three angular velocities about three axes and $I$ the moment of inertia. The equations of motion are integrated using a fourth order Runge-Kutta method to obtain the predicted response of the motion of the projectile. The maximum likelihood method (references 8, 9 and 10) follows the block diagram as shown in figure 3.

The aerodynamic forces $\underline{F}$ and moments $\underline{M}$ can be expressed in terms of linear or non-linear aerodynamic coefficients which are functions of angle of attack and Mach number. The aerodynamic force coefficients are $C_x$ (axial force), $C_z$ (normal force), $C_y$ (side force), $C_{y_p}$ (magnus force), moment coefficients $C_l$ (rolling moment), $C_m$ (pitching moment), $C_n$ (yawing moment), $C_{n_p}$ (magnus moment) and damping moment coefficients are $C_{l_p}$ (roll damping), $C_{m_q}$ (pitch damping), and $C_{n_r}$ (yaw damping). The definition of these aerodynamic coefficients dictates the complexity of the model (Table 2). The details of these models are given in reference 11.

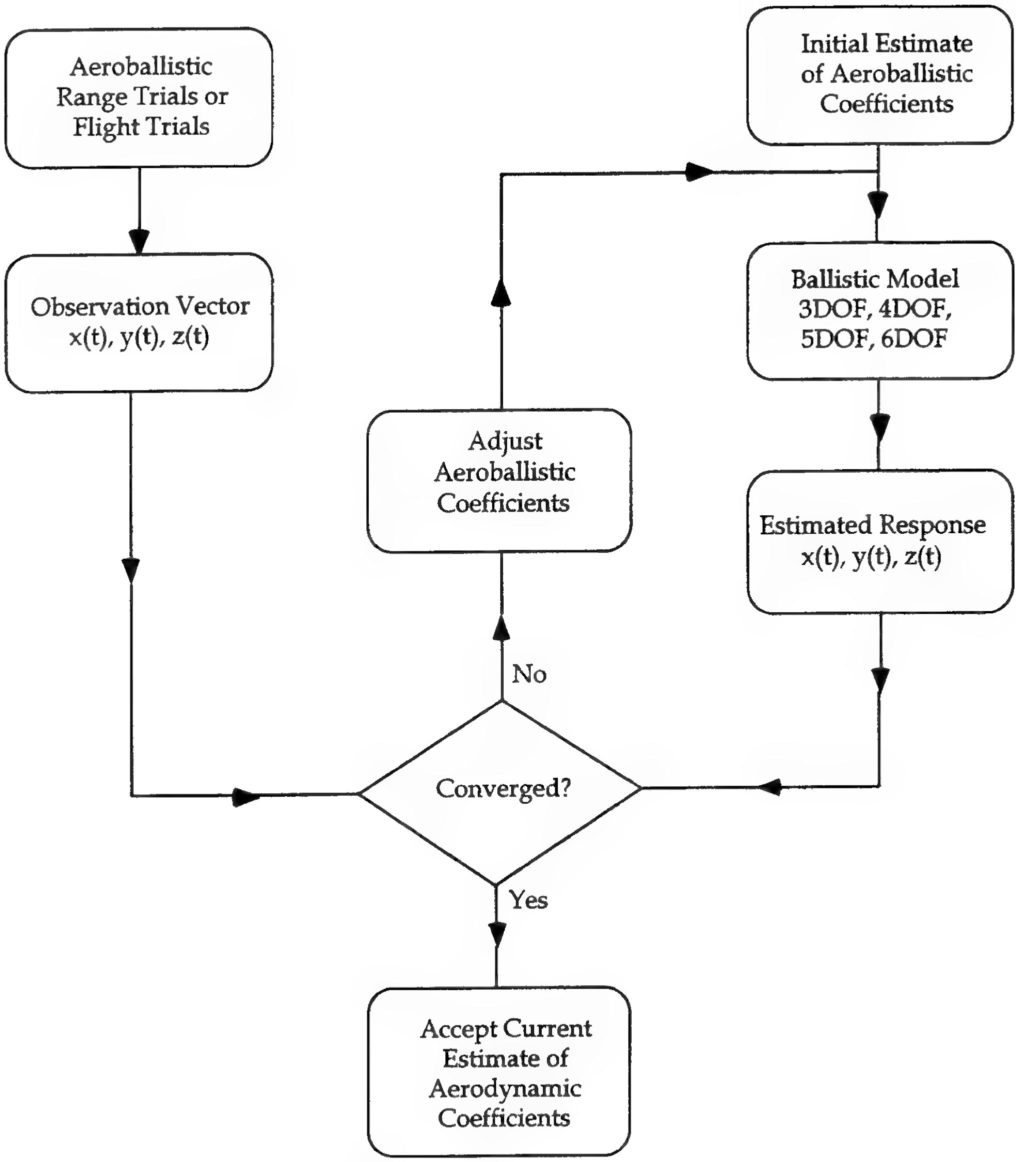


*Figure 3. Block diagram for extracting aerodynamic coefficients*

*Table 2. Definition of aerodynamic coefficient and degrees of freedom.*

| **Degrees of Freedom** | **Aerodynamic coefficient** |
|---|---|
| Six | Linear aerodynamic coefficients function of Mach number and angle of attack |
| Six | Non linear and linear aerodynamic coefficients function of Mach number and angle of attack |
| Five | Linear aerodynamic coefficients function of Mach number and angle of attack |
| Five | Non linear and linear aerodynamic coefficients function of Mach number and angle of attack |
| Four | Linear aerodynamic coefficients function of Mach number and angle of attack |
| Three | Linear aerodynamic coefficient ($C_D$) function of Mach number |

The principal interest of the trials program was to establish the aerodynamic drag characteristics of the Mk 82 bomb configuration. Hence a three degrees of freedom model was used in extracting the drag coefficients of various configurations. A brief summary of the parameter estimation model using the three degrees of freedom model is described in the next section.

# 6. 3 DOF Parameter Estimation Model

The basic assumption made in the analysis was that the angle of incidence of the projectile remained small throughout the flight so that the induced drag effects in the total drag are negligible. The equations of motion for a simple particle flying at zero incidence are

$$\ddot{X} = \left(QSC_x / m\right) \cos\theta$$

$$\ddot{Z} = g - \left(QSC_x / m\right) \sin\theta$$

The range axes system was defined as; OX down range, OZ vertically downwards and OY horizontal to the right forming a left handed co-ordinate system. At equilibrium, the forces acting on the projectile are the gravitational force, mg, and the aerodynamic force $D = QSC_x$ , where $Q = \frac{1}{2}\rho V^2$ is the dynamic pressure, $\rho$ the local air density, V the relative air velocity, $S$ the body cross sectional area and $C_x$ the aerodynamic axial force coefficient (negative of drag coefficient as the incidence is zero). The relative air velocity is

$$V^2 = \left(\dot{X} - \dot{W}_x\right)^2 + \dot{Z}^2$$

where $W_x$ is the down range component of the wind. The angle $\theta$ of elevation of the trajectory above the horizontal is given by $\tan\theta = -(\dot{Z}/\dot{X})$.

The unknown parameters ($p_i$) in the model are the initial conditions: two initial positions: $p_1 = x_0$ , $p_2 = z_0$ , Two initial velocities: $p_3 = \dot{x}_0$ , $p_4 = \dot{z}_0$ and the two forces drag and gravity $p_5 = C_x$ , $p_6 = g$ .

The importance of the sixth parameter is discussed in detail in reference 12. Briefly $p_6$ is related to the velocity and acceleration of the projectile through the frequency of the strobe units. There is a tendency for a shift in the measured frequency $f_L$ during launch because of high acceleration imposed on them (poor packaging of the electronic components). The parameter $p_6$ allows different flash rates to be used according to $f_F = f_L(g/p_6)^{1/2}$ , where g = 9.797 and $f_F$ is the altered frequency due to launch accelerations.

# 7. Results

The parameter estimation technique as applied to a particular trial's data is discussed in detail. The launch parameters for this trial are given in Table 3.

*Table 3. Typical Launch Parameters for a Trial*

| | |
|---|---|
| Mass (kg) | 15.5 |
| Muzzle Velocity (m/s) | 167 (measured by inductance coil in the muzzle)<br>169.3 (measured by WEIBEL Tracking radar) |
| Launch elevation (deg) | 20.2 |
| Temperature (°C) | 8.8 |
| Wind speed (m/s) | 1.5 |
| Wind direction (°T) | 16 |
| Flash rate (Hz) | 29.9 |

The input observation vectors for the three degrees of freedom model are the range (x) and the height (z). Typical trajectory graphs of height (z) and range (x) as functions of time for the nose strobe unit are shown in figure 4 along with the drift (y) which is not included in the present analysis. The velocities are evaluated from the positional information using a simple central difference approximation. With the initial estimate (guess) of the six unknown parameters, the 3dof model integrates the equations of motion mentioned in the previous section to obtain the predicted trajectory. The predicted trajectory is then compared with the input vector for convergence. The conditions for convergence on the six parameters are set as follows:

$\Delta p_1\ (x_0),\ \Delta p_2\ (z_0),\ = 0.015m;$
$\Delta p_3\ (\dot{x}_0),\ \Delta p_4\ (\dot{z}_0),\ = 0.1m/s;$
$\Delta p_5\ (c_x) = 0.001;\ \Delta p_6\ (g) = 0.0001$

Figure 5 shows the comparison between the input trajectory and that of the model output. The agreement between them is excellent. The differences in range $(\Delta x)$ and height $(\Delta z)$ are plotted in figure 6 as a function of time. It can be seen that the difference in range values are more than those obtained for height but they are well within the values set for convergence criteria.

The values obtained for the six parameters are shown in Table 4 together with the estimated standard deviation for each. The converged drag coefficient will correspond to the launch velocity obtained from the converged axial and vertical velocities. The model thus derives a single value of drag coefficient for each trial.

The data analysis was carried out over flight ranges where the changes in the flight velocities were minimal, ensuring that the changes in $C_D$ over this section of the flight are small.

The local value of g (9.797) agrees well with that obtained from the model (9.716) implying that the flash rates are unaffected by the launch accelerations. The data have been extrapolated to the range origin to obtain the estimates of the launch conditions and these are also included in Table 4. There is excellent agreement between the estimated and nominal values for launch velocity and elevation.

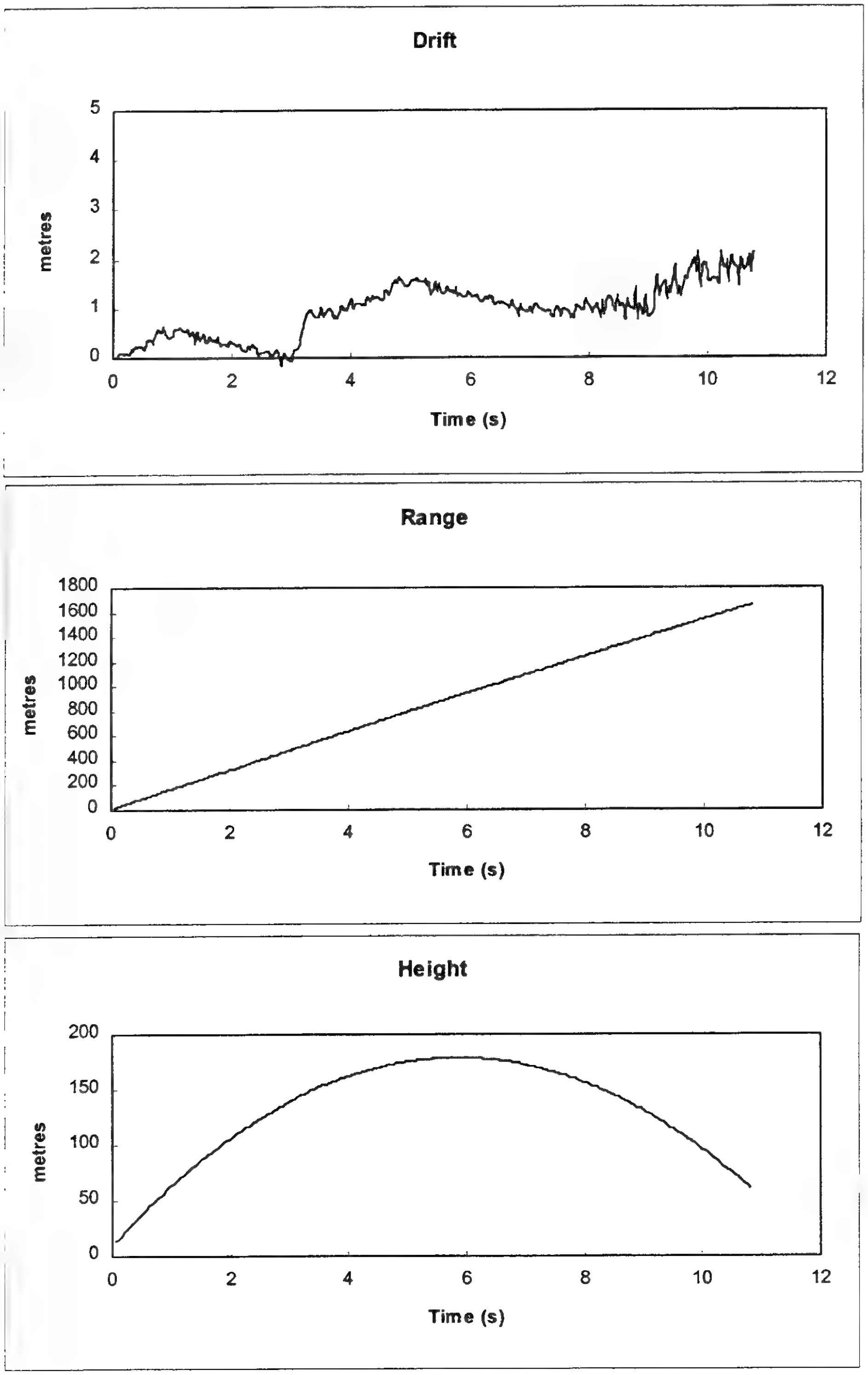


*Figure 4. Height, Range and Drift as a function of time for nose strobe unit*

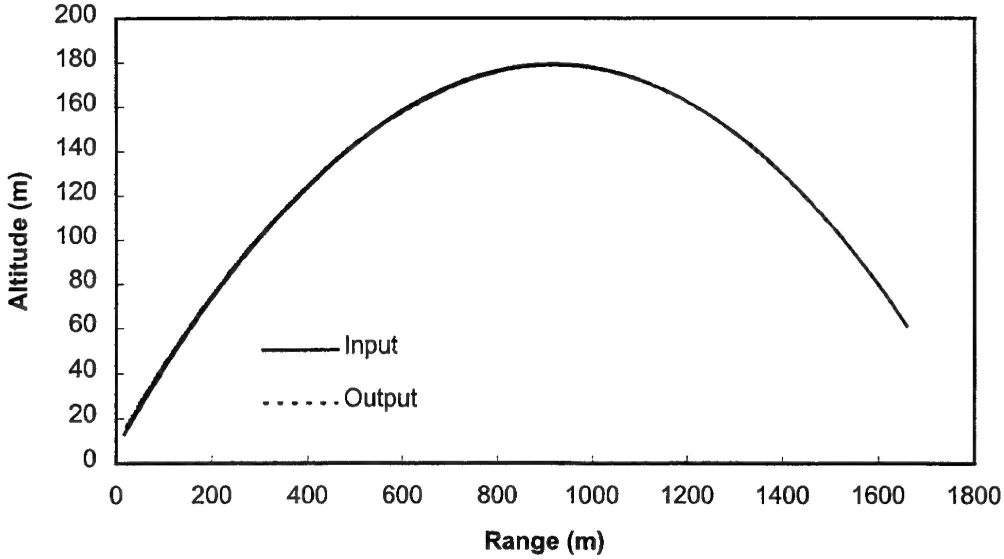


*Figure 5. Comparison of input and output trajectories of 3dof parameter estimation model*

*Table 4: 3dof model output and the corresponding standard deviation of the parameters for input data shown in Table 3.*

| Parameter | Model output | Standard deviation |
|---|---|---|
| $x_0$ (m) | 16.3 | 0.11 |
| $z_0$ (m) | 15.54 | 0.017 |
| $\dot{x}_0$ (m/s) | 160.5 | 0.049 |
| $\dot{z}_0$ (m/s) | -57.7 | 0.01 |
| $C_x$ | -0.097 | 0.00058 |
| g | 9.716 | 0.0012 |
| Launch velocity (m/s) | 171 | |
| Launch elevation ( deg) | 20.5 | |

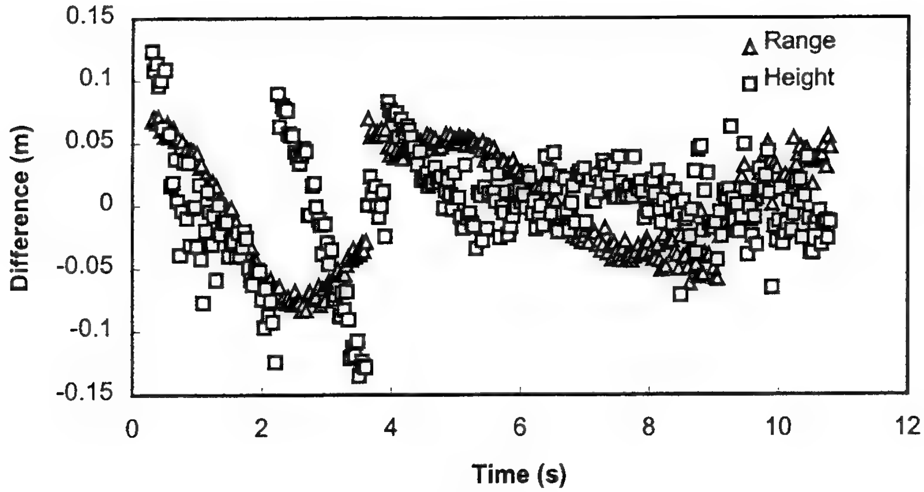


*Figure 6. Difference in range and height as a function of time between the input and output of the parameter estimation model.*

The analysis was repeated using the data obtained with the tail strobe units and the converged parameters are quite similar to those obtained using the nose strobe data. Hence an average value obtained from both the nose and tail strobe data will be used as the drag coefficient $C_D$ $(-C_x)$ for further reference.

A total of 56 half scale models of the bombs were launched, with a high launch survivability rate being achieved. The on-board instrumentation failed at launch on only 2 occasions. One failure was due to the collapse of the rear section of the model in the gun barrel, which allowed a fixing bolt to move forward and spear through the electronics package. This problem has since been rectified by strengthening those rear section components identified as being responsible for the failure, as detailed in reference 13.

There were a very small number of cases where either the front or rear strobe misfired intermittently throughout the flight duration, resulting in missing images on the camera film. However, as the rate of misfire was quite low, approximately 1 in 50, the co-ordinates of the missing images were able to be determined, with negligible induced error, by interpolation during the film reading process.

# 8. Drag Coefficient of a Clean Mk82 GPLD

The main objective of this work was to establish the drag characteristics of the Mk82 GPLD store in its operational configurations, which are a combination of a clean store with add ons such as fuzes and lugs. Hence, some effort was applied to characterising the drag characteristics of the clean configuration.

The drag variation as a function of Mach number derived from half-scale aeroballistic range trials is shown in figure 7 for the clean Mk82 GPLD store. These were obtained from trials conducted at various launch velocities (Mach numbers) and also by analysing different portions of the trajectory. Also included in the figure is the drag data that was provided as the Government Furnished Information (GFI) to the F-111C AUP contractors, Rockwell International. It can be seen that there is very good agreement with GFI up to a Mach number of 0.9. At transonic and supersonic Mach numbers the aeroballistic range trials values are less than the GFI.

The drag values obtained from the aeroballistic range facility have to be corrected for the full scale Reynolds Number. Reference 14 outlines an empirical correction procedure for correcting axial (drag) force coefficients obtained from scaled models. The correction procedure requires information about the boundary layer transition locations on the model and that of the full scale bomb. It is reasonable to assume that the transition occurs very close to the nose in the real bomb as they have a rough and wavy surface finish from casting. The half scale models with nose fuze will have its transition location very close to the nose. The prediction of transition location for the half scale models is difficult as they have a very smooth surface finish with no discernible surface discontinuity.

Following the empirical correction as outlined in Reference 14, the nature of correction for a test Mach number of 0.8 is shown in figure 8 as a function of transition length. It can be seen that the drag coefficient increases by 25% if the transition location differs by about a quarter of the bomb length. The order of correction increases with increase in Mach number. Since the precise location for transition for a clean Mk 82 half scale model is unknown, it was decided to present only uncorrected results obtained from the parameter estimation program.

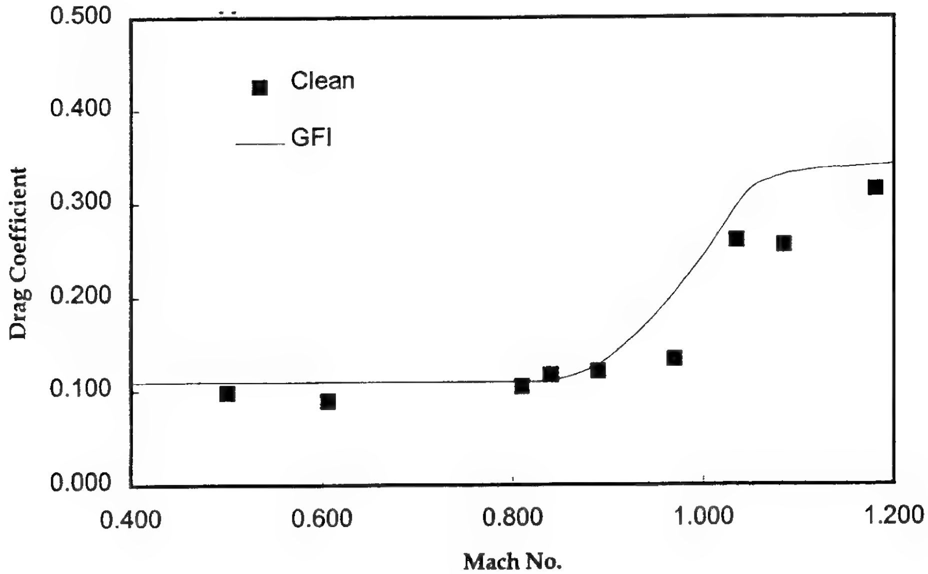


*Figure 7. Drag coefficient as a function of Mach number for a clean Mk82 GPLD configuration. Full line is the database furnished to contractors, Rockwell International.*

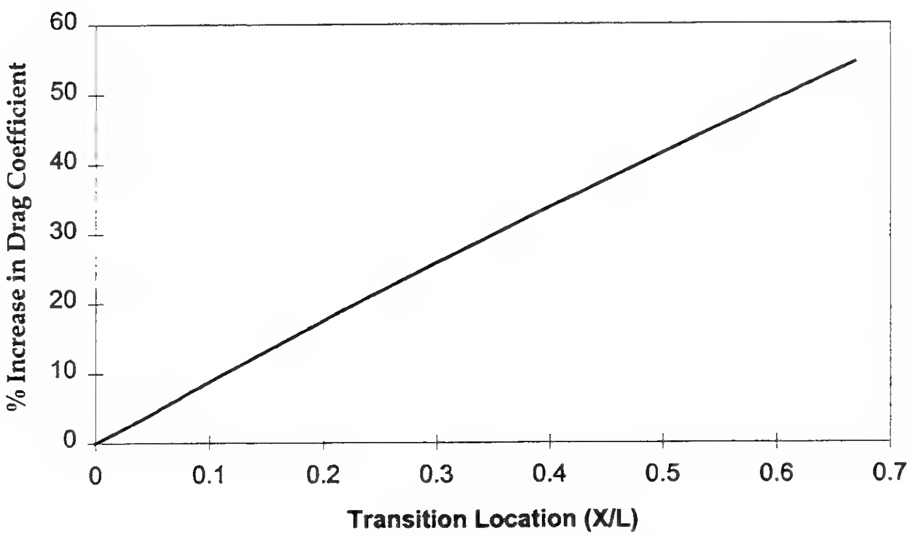


*Figure 8. Reynolds number Correction to Drag coefficient as a function of non-dimensional transition length*

# 9. Drag coefficient of various Mk82 configurations

## 9.1 F111-C Configurations

Figure 9 shows the drag characteristics of various Mk 82 configurations derived from half-scale aeroballistic range trials. It can be seen that the addition of type T suspension lugs increases the drag coefficient by 50% over the range of test Mach numbers. The presence of T-Lugs and the M904 type of nose fuze causes an increase in drag coefficient of about 100% over the clean configuration. A further small increase of drag in the higher Mach number region (M>0.7) is noticeable when the store is fully configured (T-Lugs, M904 type nose fuze and M905 type tail fuze with the drive assembly). These quoted percentages were obtained after fitting trend lines of linear type to the experimental data over the range 0.4<M<0.95.

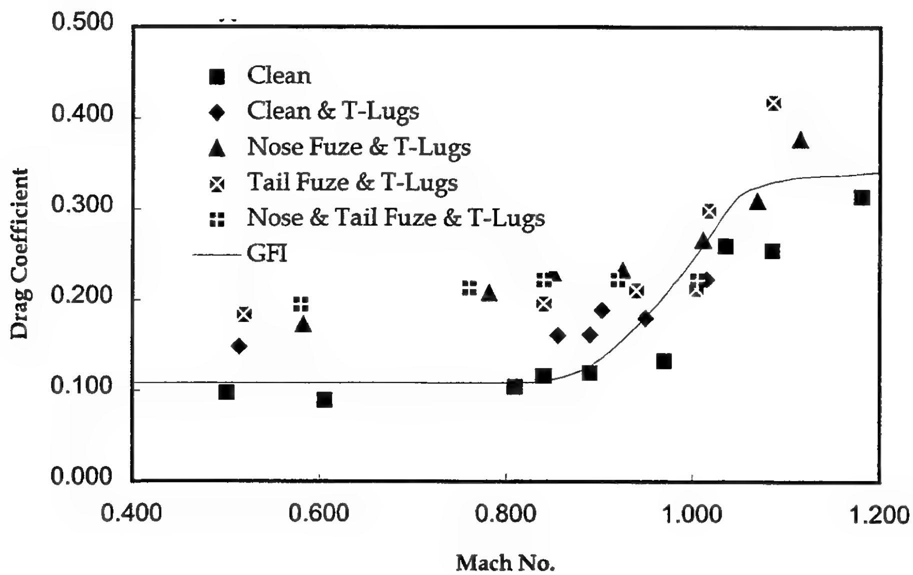


*Figure 9. Drag coefficient as a function of Mach number for various Mk 82 GPLD configurations related to F111-C aircraft*

## 9.2 F/A-18 Configurations

The aerodynamic drag characteristics of Mk 82 GPLD store configurations carried by F/A-18 aircraft is shown in figure 10 as derived from half-scale aeroballistic range trials. Only limited trials were conducted to infer the effect of D-Lugs and the position of fin orientation with respect to suspension lugs. Further, these trials will supplement the aerodynamic data obtained from the full scale Mk 82 bomb releases from F/A-18 aircraft (the data analysis of the full scale release from F/A-18 aircraft can be found in a separate report).

The drag characteristics of F/A-18 configurations of Mk 82 GPLD bomb are similar to those of F-111C configurations, except that their individual values are slightly lower. The addition of D-type of suspension lugs increases the drag by about 25% over the clean configuration in the Mach number range 0.5<M<0.8, whereas the T-lugs causes an increase of 50%. The smaller increase can be attributed to the streamlined nature of D-Lugs as compared to the bluff T-Lugs. Similar argument is applicable when the nose fuze or tail fuze are added to the clean configuration.

Generally it can be concluded that the drag of F/A-18 configurations is less than that of F-111C counterparts, mainly because of the presence of the bluff T-Lugs.

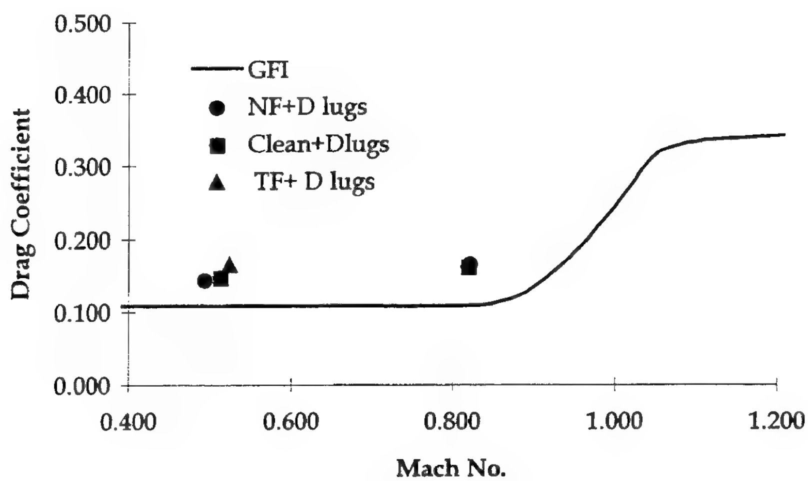


*Figure 10. Drag coefficient as a function of Mach number for various Mk 82 GPLD configurations related to F/A-18 aircraft.*

### 9.3 Discussions

Despite the Mk 82 bomb being in service over long periods, reference 15 states that there is very little data existing anywhere on the free stream aerodynamics of the bomb. This lack of data along with the RAAF's configurational differences has led to the evaluation of free stream aerodynamic drag data using the half scale models in DSTO's aeroballistic range facility.

The drag characteristics of the clean Mk 82 GPLD baseline configuration were initially established and the subsequent tests with the lugs and fuzes provided the valuable insight into the incremental changes. The drag force increment are found to have a magnitude approximately equal to the sum of the individual increments. Similar trends were observed for the wind tunnel tests on the Mk 82 models conducted by AOD (ref 16, 17) and previous studies conducted in aeroballistic range trials (ref 18), even though there are differences in their absolute magnitude.

The present study has established the increase in drag due to incremental changes to the configuration. Any future modification for the Mk 82 bomb, such as a change of fuzes (e.g. FMU-54/B in place of M904), will require only limited tests to determine drag characteristics.

## 10. Acknowledgments

The authors wishes to acknowledge all those who participated in the aeroballistic range testing of the half scale Mk 82 bomb. In particular, we appreciate the help of J.Leathem (electronics and trials coordinator), J.Leach (camera coordinator), N. Potticary (gas gun operations and range safety) and all those who participated and assisted.

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| 4. AUTHOR(S)<br><br>L.V.Krishnamoorthy, R.Glass and D.R.Kirk | | | 5. CORPORATE AUTHOR<br><br>Aeronautical and Maritime Research Laboratory<br>PO Box 4331<br>Melbourne Vic 3001 | | |
| 6a. DSTO NUMBER<br>DSTO-TR-0545 | 6b. AR NUMBER<br>AR-010-249 | | 6c. TYPE OF REPORT<br>Technical Report | 7. DOCUMENT DATE<br>June 1997 | |
| 8. FILE NUMBER<br>J9505/13/28 | 9. TASK NUMBER<br>ADA 95/268 | 10. TASK SPONSOR<br>FD-Aerospace | 11. NO. OF PAGES<br>21 | 12. NO. OF REFERENCES<br>18 | |
| 13. DOWNGRADING/DELIMITING INSTRUCTIONS<br><br>None | | | 14. RELEASE AUTHORITY<br><br>Chief, Weapons Systems Division | | |
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| 16. DELIBERATE ANNOUNCEMENT<br><br>No Limitations | | | | | |
| 17. CASUAL ANNOUNCEMENT Yes | | | | | |
| 18. DEFTEST DESCRIPTORS<br><br>aerodynamic drag, F-111C Avionics Update Project, Mk 82 bombs | | | | | |
| 19. ABSTRACT<br>A method is described to determine the drag characteristics of the Mk 82 low drag bomb. This involves launching half scale models from the DSTO gas gun facilities at Port Wakefield and measuring the trajectories by photogrammetric methods. The drag coefficients were calculated from the measured positional data using a three degrees of freedom parameter estimation method. The estimated drag characteristics of various Mk 82 GPLD store configurations will form the basis of a database for use with the updated F-111C aircraft. | | | | | |